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Title:

**GROUNDING GATE FOR REDUCING DARK CURRENT IN CMOS IMAGE  
SENSORS**

Inventors:

**Chandra Mouli  
Howard Rhodes**

Thomas J. D'Amico  
DICKSTEIN SHAPIRO MORIN &  
OSHINSKY LLP  
2101 L Street NW  
Washington, DC 20037-1526  
(202) 828-2232

## **GROUNDING GATE FOR REDUCING DARK CURRENT IN CMOS IMAGE SENSORS**

### **FIELD OF THE INVENTION**

[0001] The present invention relates generally to semiconductor devices, and more particularly, to isolation technology for use in CMOS image sensors.

### **BACKGROUND OF THE INVENTION**

[0002] In silicon integrated circuit (IC) fabrication, it is often necessary to isolate devices that are formed in a single substrate from one another. The individual devices or circuit components subsequently are connected to other circuit elements to create a specific circuit configuration. This is true for the individual pixels of a CMOS image sensor.

[0003] A CMOS image sensor circuit includes a focal plane array of pixel cells, each one of the cells including either a photogate, photoconductor, or photodiode overlying a charge accumulation region within a substrate for accumulating photo-generated charge. Each pixel cell may include a transistor for transferring charge from the charge accumulation region to a floating diffusion node and a transistor, for resetting the diffusion node to a predetermined charge level prior to charge transference. The pixel cell may also include a source follower transistor for receiving and amplifying charge from the diffusion node and an access transistor for controlling the readout of the cell contents from the source follower transistor.

[0004] In a CMOS image sensor, the active elements of a pixel cell perform the necessary functions of: (1) photon to charge conversion; (2) accumulation of image charge; (3) transfer of charge to the floating diffusion node accompanied by charge amplification; (4) resetting the floating diffusion node to a known state before the transfer of charge to it; (5) selection of a pixel for readout; and (6) output and amplification of a signal representing pixel charge from the

floating diffusion node. Photo charge may be amplified when it moves from the initial charge accumulation region to the floating diffusion node. The charge at the floating diffusion node is typically converted to a pixel output voltage by the source follower output transistor. The photosensitive element of a CMOS image sensor pixel is typically either a depleted p-n junction photodiode or a field induced depletion region beneath a photogate.

[0005] CMOS image sensors of the type discussed above are generally known as discussed, for example, in Nixon et al., "256.times.256 CMOS Active Pixel Sensor Camera-on-a-Chip," IEEE Journal of Solid-State Circuits, Vol. 31(12), pp. 2046-2050 (1996); and Mendis et al., "CMOS Active Pixel Image Sensors," IEEE Transactions on Electron Devices, Vol. 41(3), pp. 452-453 (1994). See also U.S. Patent Nos. 6,177,333 and 6,204,524 which describe operation of conventional CMOS imagers, the contents of which are incorporated herein by reference.

[0006] CMOS image pixels must be isolated from one another to avoid pixel cross talk. In the case of CMOS image sensors, which are intentionally fabricated to be sensitive to light, it is advantageous to provide both electrical and optical isolation between pixels.

[0007] Shallow trench isolation (STI) is one technique, which can be used to isolate pixels from one another. In general, a trench is etched into the substrate and filled with a dielectric to provide a physical and electrical barrier between adjacent pixels. Refilled trench structures, for example, are formed by etching a trench by a dry anisotropic or other etching process and then filling it with a dielectric such as a chemical vapor deposited (CVD) or high density plasma (HDP) silicon oxide or silicon dioxide ( $\text{SiO}_2$ ). The filled trench is then planarized by a chemical mechanical planarization (CMP) or etch-back process so that the dielectric remains only in the trench and its top surface remains level with that of the silicon substrate.

[0008] To enhance the isolation further, ions can be implanted in the silicon substrate in the area directly beneath the trench. However, a drawback associated with ion implantation beneath the trench, as noted, for example, in S. Nag et al., "Comparative Evaluation of Gap-Fill Dielectrics in Shallow Trench Isolation for Sub-0.25  $\mu\text{m}$  Technologies," IEEE IEDM, pp. 841-844 (1996), is that ion implantation beneath the trench can result in high current leakage. In particular, when ions are implanted in the substrate close to the edges of the trench, current leakage can occur at the junction between the active device regions and the trench.

[0009] In addition to the above-mentioned drawbacks, the dominant crystallographic planes along the trench sidewalls, which have a higher silicon density, create a higher density of trap sites along the trench sidewalls compared to silicon/gate oxide interface of a transistor at the silicon surface. Trap sites on dangling bonds or broken bonds can exist at the gate electrode/oxide interface, in the bulk oxide film, the oxide substrate interface, and/or the trench insulation/active layer interface. The trap sites are normally uncharged but become energetic when electrons and holes become trapped in the trap sites. Highly energetic electrons or holes are called hot carriers. Trapped hot carriers can contribute to the fixed charge of the device and change the threshold voltage and other electrical characteristics of the device. As a result of these trap sites formed along the trench sidewalls, current generation near and along the trench sidewalls can be very high. Generation current from trap sites inside or near the photodiode depletion region contributes to the total dark current. Minimizing dark current in the photodiode is important in CMOS image sensor fabrication. Accordingly, it is desirable to provide an isolation technique that prevents current generation or current leakage.

#### **BRIEF SUMMARY OF THE INVENTION**

[0010] In one aspect, the invention provides an isolation gate formed over an isolation trench formed in an image sensor substrate for biasing the substrate at

the sidewalls of the trench and providing improved isolation between adjacent pixels. In another aspect, the invention provides a substrate biasing isolation gate formed over a substantial portion of an isolation trench formed in an image sensor substrate and formed surrounding a substantial portion of a photosensitive region of an image sensor pixel formed in the substrate.

[0011] These and other features and advantages of the invention will be more apparent from the following detailed description that is provided in connection with the accompanying drawings and illustrate exemplary embodiments of the invention.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

[0012] FIG. 1A is a top plan view of an exemplary CMOS image sensor fragment;

[0013] FIG. 1B is a diagrammatic side sectional view of the FIG. 1A image sensor fragment taken along line 1B-1B;

[0014] FIG. 2A is a top plan view of a CMOS image sensor fragment in accordance with a first embodiment of the invention;

[0015] FIG. 2B is a diagrammatic side sectional view of the FIG. 2A image sensor fragment taken along line 2B-2B;

[0016] FIG. 3A is a top plan view of a CMOS image sensor fragment showing a 2x2 pixel layout in accordance with a second embodiment of the invention;

[0017] FIG. 3B is a diagrammatic side sectional view of the FIG. 3A image sensor fragment taken along line 3B-3B;

[0018] FIG. 4 is a representative pixel layout showing a 1 x 1 pixel layout according to an embodiment of the invention; and

[0019] FIG. 5 is a schematic diagram of a processor system incorporating an image sensor constructed in accordance with the invention.

#### DETAILED DESCRIPTION OF THE INVENTION

[0020] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof, and in which is shown by way of illustration of specific embodiments in which the invention may be practiced. These embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized, and that structural, logical and electrical changes may be made without departing from the spirit and scope of the present invention.

[0021] The terms "wafer" and "substrate" are to be understood as including silicon, silicon-on-insulator (SOI) or silicon-on-sapphire (SOS) technology, doped and undoped semiconductors, epitaxial layers of silicon supported by a base semiconductor foundation, and other semiconductor structures. Furthermore, when reference is made to a "wafer" or "substrate" in the following description, previous process steps may have been utilized to form regions or junctions in the base semiconductor structure or foundation. In addition, the semiconductor need not be silicon-based, but could be based on silicon-germanium, germanium, or gallium-arsenide.

[0022] The term "pixel" refers to a picture element unit cell containing a photosensor and devices, such as transistors for converting electromagnetic radiation to an electrical signal. For purposes of illustration, a representative pixel is illustrated in the figures and description herein, and typically fabrication of all pixels in an imager will proceed simultaneously in a similar fashion.

[0023] Applicants propose several isolation techniques to minimize dark current and suppress leakage current in CMOS image sensors, as described below with reference to FIGS 2-5. To better illustrate these techniques, a brief description

of an exemplary CMOS image sensor pixel with which the invention can be used is described first with reference to FIGS. 1A and 1B hereinbelow.

[0024] Referring now to FIGS. 1A and 1B, a semiconductor wafer fragment of an exemplary CMOS image sensor four-transistor (4T) pixel, generally designated by reference numeral 10, is shown. The CMOS image sensor pixel 10 generally comprises a transfer gate 50 for transferring photoelectric charges generated in a pinned photodiode 21 to a floating diffusion region 25 acting as a sensing node, connected to the gate of an output source follower transistor 60, a reset transistor 40 for resetting the sensing node in order to sense a next signal, and a row select transistor 80 for outputting a signal from the source follower transistor 60 to an output terminal in response to a pixel address signal.

[0025] A view of a section of the exemplary CMOS image sensor taken along line 1B-1B of FIG. 1A is shown in FIG. 1B. The pinned photodiode is termed such since the potential in the photodiode is pinned to a constant value when the photodiode is fully depleted. The pinned photodiode has a photosensitive p-n-p junction region 21 comprising a p-type surface layer 24 and an n-type photodiode region 26 within a p-type active layer 20. The pinned photodiode includes two p-type regions 20, 24 so that the n-type photodiode region is fully depleted at a pinning voltage. Impurity doped source/drain regions 22, preferably having n-type conductivity, are provided about the gates 40, 60, 80. The floating diffusion region 25 adjacent to the transfer gate 50, is also preferably n-type.

[0026] Conventional trench isolation regions 28 are formed in the p-type substrate 20 adjacent to the p-n-p junction region 21. The trench isolation regions 28 are formed using a conventional STI process and are typically formed by etching a trench 28 in the doped active layer or substrate 20 via a directional etching process, such as Reactive Ion Etching (RIE), or etching with a preferential anisotropic etchant used to etch into the doped active layer 20 to a sufficient depth, generally about 1000 Å to 5000 Å.

[0027] The trenches are then filled with an insulating material, for example, silicon dioxide, silicon nitride, ON (oxide-nitride), NO (nitride-oxide), or ONO (oxide-nitride-oxide). The insulating materials may be formed by various chemical vapor deposition (CVD) techniques such as low pressure chemical vapor deposition (LPCVD), high density plasma (HDP) deposition, or any other suitable method for depositing an insulating material within a trench. After the trenches are filled with an insulating material, a planarizing process such as chemical mechanical polishing is used to planarize the structure. While the trench isolation regions 28 are formed by the STI process, it should be understood that the isolation regions 28 may instead be formed using the Local Oxidation of Silicon (LOCOS) process.

[0028] The gate stacks 40, 50, 60, and 80 are typically formed after the trench is formed. The order of these preliminary process steps may be varied as is required or convenient for a particular process flow, for example, if a photogate sensor which overlaps the transfer gate is desired, the gate stacks may be formed before or after the photogate; and if a nonoverlapping photogate is desired, the gate stacks may again be formed before or after photogate formation.

[0029] A translucent or transparent insulating layer 30 is formed over the CMOS image sensor. This insulating layer 30 is typically SiO<sub>2</sub>, BPSU, PSG, BSG, or SOG which is planarized. Conventional processing methods are then carried out to form, for example, contacts 32 (shown in FIG. 1A) in the insulating layer 30 to provide an electrical connection to the source/drain regions 22, the floating diffusion region 25, and other wiring to connect gate lines and other connections in the pixel 10. The contact holes are then metallized to provide electrical contact to the photogate, reset gate, transfer gate, and diffusions.

[0030] In the CMOS image sensors depicted in FIGS. 1A and 1B, electrons are generated by light incident externally and collected in the photodiode region 26. The electrons are transferred to the floating diffusion region 25 and are provided as an electrical signal by the source follower transistor 60. A maximum



output signal is proportional to the number of electrons to be extracted from the photodiode. The maximum output signal increases with increased electron capacitance or acceptability of the photodiode region 26. The electron capacity of pinned photodiodes typically depends on the doping level of the image sensor and the dopants implanted into the active layer.

[0031] A common problem associated with an image sensor pinned photodiode is the creation of dark current in an electrical connection region 23 along the sidewall 29 of the conventional trench isolation region 28. The electrical connection region 23 provides an electrical connection between the p-type surface layer 24 and the p-type active layer 20. Higher dopant concentrations increase the flow of holes through the connection region 23 which increases the electron accumulation capacity of the photodiode. Dark current is strongly dependent on the doping implantation conditions of the CMOS image sensor. However, the higher dopant concentrations used in conventional image sensors also increase dark current in the electrical connection region 23. The invention provides novel techniques for improved electrical connection along the electrical connection region 23 without having to increase dopant concentrations.

[0032] Another problem associated with CMOS image sensors may occur when ion implantation is used to further enhance isolation. The polysilicon gates, trench isolation regions, source/drain regions, and diffusion regions may be heavily doped after various fabrication steps via a masked ion implantation. In addition to this doping, in conventional processes, once the trench isolation regions have been formed, a masked ion implant is performed to implant ions in the areas of the substrate directly beneath the trench isolation region thus forming an implanted ion profile 34 (as shown in FIG. 1B). However, increased ion implants or doping results in an increased flat band or threshold voltage shift.

[0033] There are limits to the amount of threshold voltage shift  $V_t$  that a device will tolerate before it will fail. A reference or supply voltage, for example,

$V_{DD}$ , to voltage shift  $V_t$  margin dictates the speed of a CMOS image sensor. Accordingly, it would be ideal to have a threshold voltage shift that is as low as possible. For example, a threshold voltage shift of 0.25mV or less is desirable for CMOS image sensors. The invention further provides novel techniques for reducing threshold voltage shifts. Although the invention is described below for use in a CMOS image sensor as the preferred embodiment, the invention is not limited to such and may be used in any suitable image sensor, for example, a CCD sensor.

[0034] A first embodiment according to the invention is now described with reference to FIGS. 2A and 2B. A region rich in positively charged holes is created along the STI sidewall 129 without increasing the dopant levels of the active layer 120. As shown in FIGS. 2A and 2B, an isolation gate 170, generally designated 170 is provided over the trench isolation region 128 and adjacent to the p-n-p junction region 121 in order to provide separation between adjacent pixels 100. The isolation gate 170 is preferably also provided slightly over an electrical connection region 123 to provide hole accumulation in this region 123. The isolation gate 170 is preferably a stacked gate including an insulating layer 176 formed over an electrode layer 174 provided over a gate oxide layer 172. Oxide, nitride, or other insulating spacers 178 are provided on either side of the isolation gate 170.

[0035] The electrode layer 174 of the isolation gate 170 may be any type of conductor compatible with the CMOS image sensor materials chosen, and is preferably formed of the same material as the other gates. Suitable materials for the electrode layer 174 include, polysilicon, poly/TiSi<sub>2</sub>, poly/WSi<sub>2</sub>, poly/WN<sub>x</sub>/W, poly/WN<sub>x</sub>, poly/CoSi<sub>2</sub> and poly/MoSi<sub>2</sub>. The isolation gate 170 may be formed at the same time as other gates, for example, the isolation gate 170, reset gate 140, the source follower 160, and the transfer gate 150 may be formed at the same time. In processes where the isolation gate 170 is formed at the same time as the other gates, it is preferred that the isolation trench regions 128 are formed prior to formation of the gates, and accordingly it is preferred that the isolation gate 170 is formed

subsequent the formation of the underlying isolation trench regions 128. A translucent or transparent insulating layer 130 is formed over the CMOS image sensor. Conventional processing steps may then be carried out to complete formation of the image sensor.

[0036] The isolation gate 170 is biased by providing a grounded potential or applying a slight potential to the isolation gate. The potential may be positive or negative depending on the conductivity of the gate type electrode as explained below. Biasing the isolation gate provides electrical isolation between adjacent pixels separated by the isolation gate 170 and corresponding isolation region 128 by causing holes to accumulate in the electrical connection region 123. The accumulation of holes increases the area of the electrical connection region 123 by creating a greater separation between the photodiode region 126 and the STI sidewall 129. The accumulation of holes in the electrical connection region 123 also provides a good electrical connection from the p-type surface layer 124 to the p-type active layer 120.

[0037] Furthermore, the depth D of the trench isolation region 128 may be reduced when an isolation gate 170 is used in accordance with the invention. Generally, isolation trenches have a depth of about 2500Å. However, the use of an isolation gate in accordance with the invention allows for the use of a trench having a depth D of less than about 2000Å or the use of an isolation trench may be eliminated. Thus the isolation gate 170 may be formed over the active layer 120.

[0038] In accordance with the first embodiment of the invention, where doping of the source/drain regions (not shown) and the floating diffusion region 125 are doped with an n+ type conductivity material, the electrode layer 174 of the isolation gate electrode 170 is preferably n+ type polysilicon. The isolation gate 170 may be grounded or tied to a slightly negative low reference voltage. The grounded or slightly negative voltage will cause holes to accumulate under the gate in the electrical connection region 123 and provide effective isolation between pixels.

[0039] Accordingly, and also in conformance with the first embodiment of the invention, the electrode layer 174 of the isolation gate 170 may be formed of a p-type conductivity material, for example p+ polysilicon. P-type dopants have a lower penetration shift than n-type dopants. However, the use of p-type polysilicon gates shifts the CMOS threshold voltage to more positive values. The combination of the threshold voltage shift associated with the p-type polysilicon gate dopant and the threshold voltage shift associated with additional ion implant doping is excessive and leads to device failure.

[0040] Contrary to conventional processes, the present invention does not require additional implants, such as, the implanted ion profile in the areas of the substrate directly beneath the trench isolation region. Therefore, by providing an isolation gate 170 according to the invention to enhance isolation, instead of increasing active layer dopant concentrations, a p+ polysilicon gate may be used without exceeding threshold voltage limitations.

[0041] The p+ polysilicon isolation gate may be grounded or tied to a slightly positive voltage, for example, a voltage at or lower than supply voltage  $V_{DD}$ , to create holes along the trench sidewall and ensure that a conductive channel for electrons is not formed between pixels. A slightly positive voltage will cause the conductive channel connecting the pixels to become inverted. The grounded voltage will cause holes to accumulate in the electrical connection region 123.

[0042] A second embodiment according to the invention is now described with reference to FIGS. 3A and 3B. A 2 x 2 CMOS image sensor pixel array is shown in FIG. 3A to better illustrate the invention. In accordance with the second embodiment of the invention, a region rich in positively charged holes is created along the STI sidewall 229 by providing an isolation gate 270 over the trench isolation region 228 and surrounding the p-n-p junction region 221. The isolation gate 270 is preferably provided slightly over an electrical connection region 223. The isolation gate 270 is also preferably formed to extend around the p-n-p junction

region 221 to a gate, for example, transfer gate 250, but does not contact the transfer gate, so as not to short the gates. The isolation gate 270 has a length  $L_x$  in the x-direction and length  $L_y$  in the y-direction as shown in FIG. 3A, each of which can be modified to optimize isolation. For example, the length  $L_x$  and  $L_y$  of the isolation gate 270 may be independently increased or decreased to minimize dark current and cross-talk between adjacent pixels. The isolation gate 270 preferably does not extend around the floating diffusion region 225. Preferably, the isolation gate 270 extends between pixels 200, as indicated by reference numeral 270'. As shown in FIG. 3B, the isolation gate 270 may be formed over a substantial portion of the trench isolation region 228, thus allowing the formation of a shallower trench isolation region 228 that is less than about 2000 Angstroms deep as discussed above in the description of the first embodiment.

[0043] As discussed above, the isolation gate 270 may be formed of any conductive material but is preferably formed of the same material as the other gates. The isolation gate 270 may also be formed at the same time as other gates. In processes where the isolation gate 270 is formed at the same time as the other gates, it is preferred that the isolation trench regions 228 are formed prior to formation of the gates, and accordingly it is preferred that the isolation gate 270 is formed subsequent to the formation of the underlying isolation trench regions 228. A translucent or transparent insulating layer 230 is formed over the CMOS image sensor. Conventional processing steps may then be carried out to complete the image sensor. The isolation gate 270 is also biased by providing a grounded potential or applying a slight potential to the isolation gate. The potential may be positive or negative depending on the conductivity of the gate electrode layer as described below. Biasing the isolation gate provides electrical isolation between adjacent pixels separated by the isolation gate and creates accumulation of holes in the electrical connection region 223.

[0044] Also as discussed above, the isolation gate 270 is preferably a stacked gate including an insulating layer 276 formed over an electrode layer 274

provided over a gate oxide layer 272. Oxide, nitride, or other insulating spacers 278 are provided on either side of the isolation gate 270. Where doping of the source/drain region is n-type, the electrode layer 274 of the isolation gate 270, is preferably n+ polysilicon and may be grounded or tied to a slightly negative low reference voltage. Accordingly, and as explained above, the isolation gate 270 may alternatively be a p+ polysilicon gate and may be grounded or tied to a slightly positive reference voltage, for example,  $V_{DD}$ . Again the accumulation of holes causes the electrical connection region 223 to expand, thereby providing a greater distance between the photodiode region 226 and the trench sidewalls 229, where trap sites exist.

[0045] A simplified circuit for a CMOS image sensor is described below in accordance with the invention. The circuit, includes, for example, a photodiode for accumulating photo-generated charge in an underlying portion of the substrate. It should be understood that the CMOS image sensor may include a photogate, photoconductor, or other image to charge converting device, in lieu of a photodiode, as the initial accumulator for photo-generated charge.

[0046] Referring now to FIG. 4, which shows a circuit for a 1x1 portion of a pixel array with each pixel cell being constructed in a manner shown by either of the pixels 100, 200 of FIGS. 2A-3B. The circuit of FIG. 4 shows a CMOS image sensor using a photodiode and having a pixel photodetector circuit.

[0047] The photodetector circuit is shown in part as a cross-sectional view of a CMOS image sensor. Each pixel 500 comprises a pinned photodiode 521 for performing photoelectric conversion. Transfer gates 550 are formed between n-type source/drain regions 522A, 522B. The transfer gate 550 and n-type source/drain regions 522A, 522B form the charge transfer transistors 529 which are controlled by a transfer signal TX. The n-type region 522A acts as a floating diffusion region. Reset gates 532 are formed between the n-type source/drain regions 522A, 522C. The reset gates and the source/drain regions 522A, 522C form reset transistors 531

which are controlled by a reset signal RST. The n-type source/drain region 522C is coupled to a voltage source  $V_{DD}$  via a conductor 519. It should be noted that while FIG. 4 shows the use of a transfer gate 550 and associated transistor 529, the transfer transistor 529 provides advantages, but is not required. Thus, the invention may be used in a three transistor (3T) environment where the transfer gate is omitted and the n-type charge collection region of the photodiode is converted with the n-type diffusion region 522A.

[0048] Isolation is provided between adjacent pixels by an isolation gate 570. The isolation gate 570 is coupled to a reference voltage  $V_{ISO}$ . The reference voltage  $V_{ISO}$  biases the isolation gate 570 off to accumulate holes in the electrical connection regions of the pixels. Typically, the isolation gate 570 is biased by tying the reference voltage  $V_{ISO}$  to ground potential. Where an n-type material is used to form the isolation gate 570, the isolation gate 570 can be turned off “harder” by setting the reference voltage  $V_{ISO}$  to a voltage more negative than ground. Alternatively, where a p-type isolation gate 570 is used, the isolation gate 570 can be turned off “harder” by setting the reference voltage  $V_{ISO}$  to a voltage more positive than ground. Applying a voltage that is more negative (for n-type isolation gates) or more positive (for p-type isolation gates) than ground will turn the isolation transistor off harder to help turn off a sub-threshold leakage path. Accordingly, a supply voltage  $V_{DD}$  can be used to provide a more positive potential. A typical supply voltage can range up to about 5 volts. The isolation gate 570 is provided to prevent leakage between adjacent pixels 500. Therefore, while illustrated as lying between adjacent pixels 500, it should be understood that the isolation gate 570 can be applied anywhere on the device calculated to prevent leakage effects of one pixel 500 to the next.

[0049] The pixel also includes additional transistors, for example, a source follower transistor 536 and a row select transistor 538. The transistors 536, 538 are coupled in series source to drain, with the source of the source follower transistors 536 also coupled over leads 540 to the voltage source  $V_{DD}$  and the drain of the row

select transistors 538 coupled to leads 542. The drain of the row select transistors 538 are connected via leads 542 to the drains of similar row select transistors for other pixels in a given pixel row. Load transistors 539 are also coupled between the drains of the transistors 538 and a voltage source  $V_{ss}$ . The transistors 539 are kept on by a signal  $V_{LN}$  applied to their gates.

[0050] It should be noted that in many transistors, the source and drain are essentially interchangeable, and interconnections specified herein should not be interpreted as solely limited to those described. In addition, while the transistors have been described as n-type or n-channel, it is recognized by those skilled in the art that a p-type or p-channel transistor may also be used if the structures are uniformly oppositely doped from that described. The n and p designations are used in the common manner to designate donor and acceptor type impurities which promote electron and hole type carriers respectively as the majority carriers. The "+" symbol, when used as a suffix with an impurity type shall be interpreted to mean that the doping concentration of that impurity is heavier than the doping associated with just the letter identifying the impurity type without the "+" suffix.

[0051] A typical processor based system, which includes a CMOS image sensor according to the invention is illustrated generally at 642 in FIG. 5. A processor based system is exemplary of a system having digital circuits which could include CMOS image sensors. Without being limiting, such a system could include a computer system, camera system, scanner, machine vision, vehicle navigation, video phone, surveillance system, auto focus system, star tracker system, motion detection system, image stabilization system and data compression system for high-definition television, all of which can utilize the present invention.

[0052] A processor based system, such as a computer system, for example generally comprises a central processing unit (CPU) 644, for example, a microprocessor, that communicates with an input/output (I/O) device 646 over a bus 652. The CMOS image sensor 642 also communicates with the system over bus



652. The computer system 600 also includes random access memory (RAM) 648, and, in the case of a computer system may include peripheral devices such as a floppy disk drive 654, and a compact disk (CD) ROM drive 656 or a flash memory card 657 which also communicate with CPU 644 over the bus 652. It may also be desirable to integrate the processor 654, CMOS image sensor 642 and memory 648 on a single IC chip.

[0053] The above description and drawings are only to be considered illustrative of exemplary embodiments, which achieve the features and advantages of the invention. Modification and substitutions to specific process conditions and structures can be made without departing from the spirit and scope of the invention. Accordingly, the invention is not to be considered as being limited by the foregoing description and drawings, but is only limited by the scope of the appended claims.